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INTERNATIONAL APPLICATION NO.

PCT/GB00/01164

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26 March 1999 (26.03.99)

TITLE OF INVENTION

METHOD AND APPARATUS FOR PROLONGING THE LIFE OF AN X-RAY TARGET

APPLICANT(S) FOR DO/EO/US

LOXLEY, Neil; TAYLOR, Mark; WALL, John Leonard; FRASER, Graham Vincent

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☐ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. ☐ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
 - a. ☐ is attached hereto (required only if not communicated by the International Bureau).
 - b. ☒ has been communicated by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
 - a. ☐ is attached hereto.
 - b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
 - a. ☐ are attached hereto (required only if not communicated by the International Bureau).
 - b. ☐ have been communicated by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☒ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☒ An English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)). Copy of IPER attached (filed in English).

Items 11 to 20 below concern document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A FIRST preliminary amendment.
14. ☐ A SECOND or SUBSEQUENT preliminary amendment.
15. ☒ A substitute specification.
16. ☐ A change of power of attorney and/or address letter.
17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
18. ☒ A second copy of the published international application under 35 U.S.C. 154(d)(4). (filed in English)
19. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. ☒ Other items or information:
Information Disclosure Statement by Applicant, Form PTO-1449, including International Search Report and copies of seven references;
Acknowledgment Card

"Express mail" mailing label number: ET114261746US

Date of Deposit: 26 September 2001

I hereby certify that this correspondence is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to Box PCT, Commissioner for Patents, Washington, D.C. 20231.



Meridith L. Deverman

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

5 In re Application of: Neil LOXLEY et al.)
 Application No. Unknown) Group Art Unit: Unknown
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 X-RAY TARGET) Peoria, Illinois 61602-1241
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PRELIMINARY AMENDMENT

Prior to examination, it is respectfully requested that that the application be amended as follows:

25 In the Specification

Please delete the entire Specification.

Please replace with the following substitute Specification in compliance with

30 37 C.F.R. Section 1.125(b):

METHOD AND APPARATUS FOR PROLONGING THE LIFE OF AN X-RAY TARGET

BACKGROUND OF THE INVENTION

5 This invention relates to an X-ray generator, and in particular to apparatus for prolonging the life of an X-ray target used within an X-ray generator.

Known X-ray generators comprise an electron gun, an X-ray target and an X-ray exit window. These generators produce X-rays by accelerating electrons from the electron gun into the x-ray target. X-rays are emitted from the target through the exit
10 window. Such generators may be in the form of sealed X-ray tubes, for example microfocus tubes, which are evacuated once and then sealed off, or in the form of rotating anode generators, which are permanently connected to vacuum pumps and are continuously evacuated during operation.

A major limitation to the longevity of X-ray generators is the lifetime of the
15 target. All targets degrade over time due to the effects of heat and roughening caused by the electron bombardment. There are various known methods for reducing these effects, including cooling the back of the target with flowing water or rotating the target so that no one area of the target is continuously subjected to the electron bombardment. Methods of increasing the cooling efficiency have been proposed
20 based on using high conductivity materials such as diamonds. However, these methods are not in common usage currently.

With known X-ray generators, it can take a number of minutes after switching on the machine before it has stabilized and is ready for use. As a result, many generators are simply left running throughout the day, so that the "warm-up" or
25 stabilization delay is removed. This means that the electrons are focussed on the target for long periods of time during each use of the generator, which leads to accelerated degradation of the target, even though the radiation produced by the X-ray generator is used only for short periods.

In cases where the construction of the generator permits, the target can be
30 replaced. Where the construction does not permit target replacement in a routine

procedure, then it is common practice to discard the complete tube assembly making up the X-ray generator.

In commercially available sealed tube and rotating anode generators, there is no provision to control the position of the beam on the target or to control the quality, size or shape of the focal spot on the X-ray target. The quality of the X-ray beam emitted can deteriorate rapidly with prolonged use due to contamination and damage to the target area under continuous electron bombardment.

In the case of rotating anode generators, once performance has degraded below a useful level, replacement of the target is required. This entails cost of replacement parts as well as significant down time of the generator. In the case of sealed tube generators it is necessary to discard the whole tube and replace it with a new tube.

BRIEF SUMMARY OF THE INVENTION

It is an object of the present invention to provide means to lengthen the life of a target, and thereby to lengthen the life of the X-ray generator. By controlling the position and brightness of the beam, the apparatus according to the present invention can reposition and modify the area of focus of the beam. Defocussing the beam reduces the flux per unit area of electrons on the target. Repositioning the beam enables a fresh area of the target to be exposed to electrons. The lifespan of the target is prolonged by either of these means, and the time interval between replacements of the target or of the complete tube assembly is increased.

A consequence of the approach of the present invention is that the tube is only required to run in operational condition with the target exposed to focussed electrons when the operator requires the X-ray beam to be produced.

According to the present invention, there is provided an X-ray generator comprising an electron gun, electron focussing means, a target and electronic control means, wherein the area of the target on which the focussing means causes electrons from said electron gun to impinge comprises an X-ray source, the control means being adapted to control the electron focussing means so that the X-ray source on said target may be varied in size and/or shape and/or position.

According to a first aspect of the invention the control means includes a switching means to switch the electron focussing means between a first unfocussed state in which the X-ray source has a first area and a second focussed state in which the X-ray source has a second area smaller than said first area. The second area may be a line, a spot or some other profile. The first area may be a line of greater thickness, a spot of greater diameter or some other shape.

Preferably said first area has a surface area at least twice, more preferably four times, most preferably ten times that of said second area.

According to a second aspect of the invention the control means includes a switching means to switch the electron focussing means between a plurality of focussed states, whereby in each state the X-ray source is in a corresponding discrete position on said target. The X-ray source may be in the form of a line, a spot or some other profile on the target.

The electron gun may comprise an evacuated tube around which the electron focussing means is mounted outside the vacuum. Alternatively the electron gun may comprise an evacuated tube within which the electron focussing means is mounted. The evacuated tube may be a sealed vacuum tube or may be connected to a vacuum pump which permits continuous evacuation during operation of the generator.

The electron focussing means may comprise an x-y deflection system for centering the electron beam in the tube. The electron beam focussing means may further comprise at least one electron lens, preferably an axially symmetric or round lens, and/or at least one quadripole or multipole lens for focussing the electron beam to a line focus and for steering the electron beam.

The electron beam lenses may be magnetic or electrostatic.

Preferably the target is metal, most preferably a metal selected from the group Cu, Ag, Mo, Rh, Al, Ti, Cr, Co, Fe, W, Au. The target surface may be orientated such that the plane of the target surface is perpendicular or at an angle to the axis of the X-ray tube.

According to a third aspect of the present invention there is also provided a method for extending the life of a target of an X-ray generator, wherein the generator

comprises an electron gun, electron focussing means and a target, the method comprising the steps of:

firing electrons at the target such that the area of the target on which the focussing means causes electrons from said electron gun to impinge comprises an X-ray source,

controlling the electron focussing means to move between a first unfocussed state in which the X-ray source has a first area and a second focussed state in which the X-ray source has a second area smaller than said first area, the intensity of electron impingement in the first state being sufficiently low to reduce target degradation, the intensity of electron impingement in the second state being sufficiently high such that the source produces a predetermined required level of brightness and source size on the target. The source may be a spot, a line or some other profile.

Preferably the electron beam current is substantially the same in the first and second states, while the intensity of the beam per unit area at the target is lower in the first state than in the second state.

According to a fourth aspect of the present invention there is provided a method for extending the life of a target of an X-ray generator, wherein the generator comprises an electron gun, electron focussing means and a target, the method comprising the steps of:

firing electrons at the target such that the area of the target on which the focussing means causes electrons from said electron gun to impinge comprises an X-ray source,

controlling the electron focussing means to move between a plurality of focussed states, whereby in each state the X-ray source is in a corresponding discrete position on said target, such that the intensity per unit area in each discrete position is substantially constant, and such that there is no overlap on the target between the discrete positions corresponding to each focussed state. The source may be a spot, a line or some other profile.

The lack of overlap between the discrete positions on the target means that a fresh area of target is used as a source each time the electron focussing means moves to a new state. The control of the electron focussing means may be manual but is

preferably electronic, so that each discrete position corresponds to a pre-programmed control signal applied to the electron focussing means.

BRIEF DESCRIPTION OF THE DRAWINGS

5 An embodiment of the invention will now be described, by way of example only, with reference to the accompanying figures, where:

Fig. 1 shows a schematic longitudinal section through an X-ray generator according to the invention suitable for use with a close coupled X-ray focussing system (not shown);

10 Fig. 2 shows a schematic arrangement of an X-ray generator in the focussed state;

Fig. 3 shows a schematic arrangement of an X-ray generator in the defocussed state;

15 Fig. 4 shows a schematic arrangement of an X-ray generator with the target in a first focussed position;

Fig. 5 shows a schematic arrangement of an X-ray generator with the target in a second focussed position;

Figs. 6(a) and 6(b) shows schematically a side view and plan view respectively on a sealed tube X-ray generator according to the invention; and

20 Figs. 7(a) and 7(b) shows schematically a side view and front view respectively on a rotating anode X-ray generator according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

25 With reference to Fig. 1, the X-ray generator 1 comprises an evacuated and sealed X-ray tube 2, containing an electron gun 3 and an X-ray target 4. The tube 2 has an exit window 6 through which X-rays are emitted from the target. Although the embodiment illustrated in Fig. 1 has a window 6 in front of the target 4, it is to be understood that the invention is applicable to other embodiments, for example X-ray generators in which the X-rays are emitted behind the target 4. The exit window does
30 not form part of the invention and is not further described.

The tube 2 is contained within a housing 13. The generator 1 also includes a system 7 for focussing and steering the electron beam 8 onto the target 4.

The focussing and steering system is capable of producing a well focussed beam of electrons 8 impinging on the target 4. The electron beam 8 may be focussed into a spot or a line, and the dimensions of the spot and line as well as its position may be changed electronically. In typical X-ray applications a spot focus having a diameter falling in the range 1 to 100 μm , generally 5 μm or larger, may be required. Alternatively a line focus may be achieved whose width falls in the range 0.4 mm to 1.0 mm, and length in the range 5 mm to 15 mm.

The electron beam 8 is produced by an electron gun 3 consisting of a Wehnelt electrode and cathode. The cathode may be a filament of tungsten or alloy, for example tungsten-rhenium, having either a hairpin or a staple shape. Alternatively the cathode may be an indirectly heated activated dispenser cathode, which may be flat or of other geometry, for example a rod with a domed end. The dispenser cathode has the advantage of extended lifetime and increased mechanical strength. With a flat surface the dispenser cathode has the further advantage of requiring only an approximate degree of alignment in the Wehnelt electrode.

Primary focus is achieved by an anode at a suitable distance from the electron gun.

The electron beam 8 from the gun is centered in the X-ray tube 2 by a centering coil 14 or set of quadripole lenses. Alternatively it may be centered by multipole lenses. Alternatively mechanical means may be used to center the electron beam 8. The centering lens or coil 14 may be omitted, where the electron gun 3 is such that it produced an electron beam 8 which is sufficiently aligned within the tube 2.

The electron beam 8 is then focussed to a spot of varying diameter. Focussing down to a diameter of less than 5 μm or better may be achieved by an axial focussing lens 15 of the quadripole, multipole or solenoid type.

The spot focus may be changed to a line focus with a stigmator lens 16, which may comprise a further set of quadripole or multipole lenses. Lines with an aspect ratio of greater than 10:1 are possible. A line focus spreads the load on the target. When viewed at a suitable angle, the line appears as a spot.

The lenses 15, 16 are preferably magnetic, but may be electrostatic. All the lenses are electronically controlled, enabling remote control and continuous alignment and scanning of the focal spot. Change from spot to line focus and change of beam diameter are also controlled remotely by varying the control signals to the electron focussing devices 7.

The electronic control of the lenses enables the electron beam 8 to be defocussed and/or repositioned on the target 4. As a result, the high intensity focal spot of the electron beam 8 is not continuously being directed at one particular area of the target 4, which means that the rate of degradation of the target will be significantly slower than with known X-ray generators. The electron beam 8 is only focussed at high intensity when the X-ray beam is required.

The actions of defocussing and refocussing the electron beam 8 are activated either at will by the operator by varying the power of the focussing coils, preferably by an electronic switch control, or automatically by the action of a shutter on the output side of the X-ray beam or other external event defined by the operator.

The target 4 is a metal, for example Cu, but it can be another material depending on the wavelength of the characteristic radiation required, for example Ag, Mo, Al, Ti, Rh, Cr, Co, Fe, W or Au. The target 4 is either perpendicular to the impinging electron beam 8, or may be inclined to decrease the absorption of the emitted X-rays.

In an example of a preferred embodiment of the present invention, the cathode is at negative high voltage and the electron gun 3 consists of a filament just inside the aperture 11 of a Wehnelt grid which is biased negatively with respect to the filament. The electrons are accelerated towards the anode which is at ground potential and pass through a hole in the latter and then through the tube 2 towards the target 4. Two sets of beam deflection coils 14, which may be iron-cored, are employed in two planes separated by 30 mm, mounted between the anode of the electron gun 3 and the focussing lens 15 to center the beam. Between the focussing lens 15 and the target 4 is an air-cored quadripole magnet which acts as a stigmator 16 in that it turns the circular cross-section of the beam 8 into an elongated one. This quadripole 16 can be rotated about the tube axis so as to adjust the orientation of the line focus. The beam 8

can be moved about on the target surface 4 by controlling the currents in the four coils of the quadripole 16.

With reference to Figs. 2 and 3 there is shown a tube 2, electron gun 3 and target 4, together with electron focussing means 7, which are discussed in more detail above. In the first focussed state, as shown in Fig. 2, the electron beam 8 is focussed by the focussing means 7 so that it forms a relatively small spot 20 on the target 4, the spot source being the required size for generation of X-rays for the intended purpose. In this state the X-ray generator is operational and the brightness of the emitted X-ray beam may be controlled by varying the applied power to the tube. When the generator is switched to the second unfocussed state as shown in Fig. 3, the electron beam 18 has the same power, but the focussing means does not focus the beam 18 so tightly, so that it forms a relatively larger spot source 21 on the target 4. In this state the X-ray generator is in standby mode and the intensity per unit area at the target 4 is greatly reduced. The consequent localized degradation of the target, which depends on local intensity per unit area, is also reduced.

With reference to Figs. 4 and 5 there is shown a tube 2, electron gun 3 and target 4, together with electron focussing means 7, which are discussed in more detail above. In the first focussed state, as shown in Fig. 4, the electron beam 28 is focussed by the focussing means 7 so that it forms a relatively small spot source 22 on the target 4, the spot source being the required size for generation of X-rays for the intended purpose. In this state the X-ray generator is operational and the brightness of the emitted X-ray beam may be controlled by varying the applied power to the tube. When the generator is switched to a second focussed state, as shown in Fig. 5, the electron beam 38 has the same power, but is focussed by the focussing means to a second spot source 23 on a different part of the target 4. The spot source 23 is the required size for generation of X-rays for the intended purpose, and will generally be the same size as the spot source 22 in the first state. There is no overlap between the positions of spot sources 22 and 23.

In practice there may be further operational states in which the spot source is the same size as spot sources 22, 23 but in different, non-overlapping locations. It may be possible to fit as many as ten or more non-overlapping sources on a target,

target. This enables the power density loading on the target 32 to be reduced when the X-rays are not being used, or for new areas of the target 32 to be periodically exposed when the previously exposed area becomes damaged or degraded. In Fig. 6 the coils 34 are shown as being external to the vacuum. In this way it is possible for the focussing coils 34 to be retrofitted to an existing generator, in order to prolong the life of the generator. However the scope of the invention includes the case where the coils 34 are built in to the generator and provided inside the vacuum enclosure 30.

Figs. 7(a) and 7(b) shows schematically a side view and front view respectively on a conventional rotating anode X-ray generator. The generator comprises a continuously pumped vacuum chamber 40 containing an electron gun 41 and a target 42 deposited on a cylindrical anode 43 which rotates at high speed. Adjacent to the anode are X-ray transparent windows 44, through which X-rays 46 are transmitted. Surrounding the vacuum chamber between the electron gun 41 and target 42 is an electrostatic or electromagnetic lens. The anode 43 is water cooled (not shown). The rotation of the anode 43 dissipates more effectively the heat generated on the target 42, so that increased power loading of the target and hence increased X-ray brightness are possible.

The electrostatic or electromagnetic lens comprises one or more sets of focussing coils 45 arranged outside the vacuum chamber 40. The coils 45 serve the same purpose as the coils 34 described with reference to Fig. 6 above, and may also be retrofitted or fitted within the vacuum chamber, i.e., the coils may be internal or external.

These and other modifications and improvements can be incorporated without departing from the scope of the invention.

CLAIMS

1. An x-ray generator comprising an electron gun, electron focusing means, a target and electronic control means, wherein an area of the target on which the focusing means causes electrons from said electron gun to impinge comprises an x-ray source emitting an x-ray beam, the control means being adapted to control the electron focusing means so that the x-ray source on said target may be varied in size, wherein the x-ray generator further comprises a shutter to control the emitted x-ray beam, and wherein the control means includes a switching means to switch the electron focusing means between a first unfocused state in which the x-ray source has a first area upon action of the shutter and a second focused state in which the x-ray source has a second area smaller than said first area when the shutter is open.

2. The x-ray generator according to Claim 1, wherein said first area has a surface area at least twice that of said second area.

3. The x-ray generator according to Claim 1, wherein said first area has a surface area at least four times that of said second area.

4. The x-ray generator according to Claim 1, wherein said first area has a surface area at least ten times that of said second area.

5. An x-ray generator comprising an electron gun, electron focusing means, a target and electronic control means, wherein the area of the target on which the focusing means causes electrons from said electron gun to impinge comprises an x-ray source generating an x-ray beam output, the control means being adapted to control the electron focusing means so that the x-ray source on said target may be varied in size, wherein the control means includes a switching means to switch the electron focusing means between a plurality of focused states, whereby in each state the x-ray source is in a corresponding discrete stationary position on said target.

6. The x-ray generator according to Claim 5, wherein the electron gun comprises an evacuated tube, and wherein the electron focusing means comprises an x-y deflection system for centering the electron beam in the tube.

7. The x-ray generator according to Claim 6, wherein the electron beam focusing means further comprises at least one electron lens.

8. The x-ray generator according to Claim 7, wherein said electronic lens comprises an axially symmetric or round lens for focusing the electron beam to a line focus and for steering the electron beam.

9. The x-ray generator according to Claim 7, wherein said electron lens comprises at least one quadripole or multipole lens for focusing the electron beam to a line focus and for steering the electron beam.

10. The x-ray generator according to Claim 5, wherein the target is a metal selected from the group Cu, Ag, Mo, Rh, Al, Ti, Cr, Co, Fe, W, Au.

11. A method for extending the life of a target of an x-ray generator, wherein the generator comprises an electron gun, electron focusing means and a target, the method comprising the steps of:

firing electrons at the target such that the area of the target on which the focusing means causes electrons from said electron gun to impinge comprises an x-ray source emitting an x-ray beam,

controlling the emitted x-ray beam by action of a shutter in its path, and controlling the electron focusing means by the action of the shutter to move between a first unfocused state in which the x-ray source has a first area and a second focused state in which the x-ray source has a second area smaller than said first area, the intensity of electron impingement in the first state being sufficiently low to reduce target degradation, the intensity of electron impingement in the second state being

sufficiently high such that the source produces a predetermined required level of brightness and source size on the target.

12. The method according to Claim 11, wherein the electron beam current is
5 substantially the same in the first and second states, while the intensity of the beam per unit area at the target is lower in the first state than in the second state.

13. A method of extending the life of a target of an x-ray generator, wherein
10 the generator comprises an electron gun, electron focusing means and a target, the method comprising the steps of:

firing electrons at the target such that the area of the target on which the
focusing means causes electrons from said electron gun to impinge comprises an x-ray
source, and

controlling the electron focusing means to move between a plurality of focused
15 states, whereby in each state the x-ray source is in a corresponding discrete stationary position on said target, such that the intensity per unit area in each discrete position is substantially constant, and such that there is no overlap on the target between the discrete positions corresponding to each focused state.

METHOD AND APPARATUS FOR PROLONGING THE LIFE OF AN X-RAY TARGET

ABSTRACT OF THE DISCLOSURE

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10 An X-ray generator comprises an evacuated and sealed X-ray tube, containing an electron gun and an X-ray target. An electron beam is produced by the electron gun in which the cathode is at negative high voltage, the electron gun consisting of a filament just inside the aperture of a Wehnelt grid which is biased negatively with respect to the filament. Two sets of beam deflection coils, are employed in two planes, mounted between the anode of the electron gun and the focussing lens to center the beam. Between the focussing lens and the target is an air-cored quadripole magnet which acts as a stigmator in that it turns the circular cross-section of the beam into an elongated one. This quadripole can be rotated about the tube axis so as to
15 adjust the orientation of the line focus. The beam can be moved about on the target surface by controlling the currents in the four coils of the quadripole.

1. *Phragmites australis* (Cav.) Trin. ex Steud.
 2. *Spartina patens* (Muhl.) Bosc.
 3. *Spartina alterniflora* (Lois.) Bosc.
 4. *Spartina cynosuroides* (L.) Bosc.
 5. *Spartina anglica* (L.) Bosc.
 6. *Spartina pectinata* (L.) Bosc.
 7. *Spartina rostrata* (L.) Bosc.
 8. *Spartina rigida* (L.) Bosc.
 9. *Spartina foliosa* (L.) Bosc.
 10. *Spartina densa* (L.) Bosc.
 11. *Spartina angustata* (L.) Bosc.
 12. *Spartina gracilis* (L.) Bosc.
 13. *Spartina robusta* (L.) Bosc.
 14. *Spartina stricta* (L.) Bosc.
 15. *Spartina serotina* (L.) Bosc.
 16. *Spartina angustata* (L.) Bosc.
 17. *Spartina gracilis* (L.) Bosc.
 18. *Spartina robusta* (L.) Bosc.
 19. *Spartina stricta* (L.) Bosc.
 20. *Spartina serotina* (L.) Bosc.
 21. *Spartina angustata* (L.) Bosc.
 22. *Spartina gracilis* (L.) Bosc.
 23. *Spartina robusta* (L.) Bosc.
 24. *Spartina stricta* (L.) Bosc.
 25. *Spartina serotina* (L.) Bosc.
 26. *Spartina angustata* (L.) Bosc.
 27. *Spartina gracilis* (L.) Bosc.
 28. *Spartina robusta* (L.) Bosc.
 29. *Spartina stricta* (L.) Bosc.
 30. *Spartina serotina* (L.) Bosc.
 31. *Spartina angustata* (L.) Bosc.
 32. *Spartina gracilis* (L.) Bosc.
 33. *Spartina robusta* (L.) Bosc.
 34. *Spartina stricta* (L.) Bosc.
 35. *Spartina serotina* (L.) Bosc.
 36. *Spartina angustata* (L.) Bosc.
 37. *Spartina gracilis* (L.) Bosc.
 38. *Spartina robusta* (L.) Bosc.
 39. *Spartina stricta* (L.) Bosc.
 40. *Spartina serotina* (L.) Bosc.
 41. *Spartina angustata* (L.) Bosc.
 42. *Spartina gracilis* (L.) Bosc.
 43. *Spartina robusta* (L.) Bosc.
 44. *Spartina stricta* (L.) Bosc.
 45. *Spartina serotina* (L.) Bosc.
 46. *Spartina angustata* (L.) Bosc.
 47. *Spartina gracilis* (L.) Bosc.
 48. *Spartina robusta* (L.) Bosc.
 49. *Spartina stricta* (L.) Bosc.
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 54. *Spartina stricta* (L.) Bosc.
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 62. *Spartina gracilis* (L.) Bosc.
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 66. *Spartina angustata* (L.) Bosc.
 67. *Spartina gracilis* (L.) Bosc.
 68. *Spartina robusta* (L.) Bosc.
 69. *Spartina stricta* (L.) Bosc.
 70. *Spartina serotina* (L.) Bosc.
 71. *Spartina angustata* (L.) Bosc.
 72. *Spartina gracilis* (L.) Bosc.
 73. *Spartina robusta* (L.) Bosc.
 74. *Spartina stricta* (L.) Bosc.
 75. *Spartina serotina* (L.) Bosc.
 76. *Spartina angustata* (L.) Bosc.
 77. *Spartina gracilis* (L.) Bosc.
 78. *Spartina robusta* (L.) Bosc.
 79. *Spartina stricta* (L.) Bosc.
 80. *Spartina serotina* (L.) Bosc.
 81. *Spartina angustata* (L.) Bosc.
 82. *Spartina gracilis* (L.) Bosc.
 83. *Spartina robusta* (L.) Bosc.
 84. *Spartina stricta* (L.) Bosc.
 85. *Spartina serotina* (L.) Bosc.
 86. *Spartina angustata* (L.) Bosc.
 87. *Spartina gracilis* (L.) Bosc.
 88. *Spartina robusta* (L.) Bosc.
 89. *Spartina stricta* (L.) Bosc.
 90. *Spartina serotina* (L.) Bosc.
 91. *Spartina angustata* (L.) Bosc.
 92. *Spartina gracilis* (L.) Bosc.
 93. *Spartina robusta* (L.) Bosc.
 94. *Spartina stricta* (L.) Bosc.
 95. *Spartina serotina* (L.) Bosc.
 96. *Spartina angustata* (L.) Bosc.
 97. *Spartina gracilis* (L.) Bosc.
 98. *Spartina robusta* (L.) Bosc.
 99. *Spartina stricta* (L.) Bosc.
 100. *Spartina serotina* (L.) Bosc.

5 In view of the above, it is respectfully believed that all the presently submitted claims are allowable and a Formal Notice of Allowance is courteously solicited. It is believed that the application is in condition for allowance; however, if the Examiner feels otherwise, a telephone interview is respectfully requested. An early notice of allowance is solicited.

10

15

20

Version With Markings to Show Changes Made

Following is a marked-up version of the entire Specification with all changes shown by conventional comparison (underling and bracketing):

10/27/09 10:00:00

METHOD AND APPARATUS FOR PROLONGING THE LIFE OF AN X-RAY TARGET

BACKGROUND OF THE INVENTION

5 This invention relates to an X-ray generator, and in particular to apparatus for prolonging the life of an X-ray target used within an X-ray generator.

Known X-ray generators comprise an electron gun, an X-ray target and an X-ray exit window. These generators produce X-rays by accelerating electrons from the electron gun into the x-ray target. X-rays are emitted from the target through the exit
10 window. Such generators may be in the form of sealed X-ray tubes, for example microfocus tubes, which are evacuated once and then sealed off, or in the form of rotating anode generators, which are permanently connected to vacuum pumps and are continuously evacuated during operation.

A major limitation to the longevity of X-ray generators is the lifetime of the
15 target. All targets degrade over time due to the effects of heat and roughening caused by the electron bombardment. There are various known methods for reducing these effects, including cooling the back of the target with flowing water or rotating the target so that no one area of the target is continuously subjected to the electron bombardment. Methods of increasing the cooling efficiency have been proposed
20 based on using high conductivity materials such as diamonds. However, these methods are not in common usage currently.

With known X-ray generators, it can take a number of minutes after switching on the machine before it has [stabilised] stabilized and is ready for use. As a result, many generators are simply left running throughout the day, so that the "warm-up" or
25 [stabilisation] stabilization delay is removed. This means that the electrons are focussed on the target for long periods of time during each use of the generator, which leads to accelerated degradation of the target, even though the radiation produced by the X-ray generator is used only for short periods.

In cases where the construction of the generator permits, the target can be
30 replaced. Where the construction does not permit target replacement in a routine

procedure, then it is common practice to discard the complete tube assembly making up the X-ray generator.

In commercially available sealed tube and rotating anode generators, there is no provision to control the position of the beam on the target or to control the quality, size or shape of the focal spot on the X-ray target. The quality of the X-ray beam emitted can deteriorate rapidly with prolonged use due to contamination and damage to the target area under continuous electron bombardment.

In the case of rotating anode generators, once performance has degraded below a useful level, replacement of the target is required. This entails cost of replacement parts as well as significant down time of the generator. In the case of sealed tube generators [t] it is necessary to discard the whole tube and replace it with a new tube.

BRIEF SUMMARY OF THE INVENTION

It is an object of the present invention to provide means to lengthen the life of a target, and thereby to lengthen the life of the X-ray generator. By controlling the position and brightness of the beam, the apparatus according to the present invention can reposition and modify the area of focus of the beam. Defocussing the beam reduces the flux per unit area of electrons on the target. Repositioning the beam enables a fresh area of the target to be exposed to electrons. The lifespan of the target is prolonged by either of these means, and the time interval between replacements of the target or of the complete tube assembly is increased.

A consequence of the approach of the present invention is that the tube is only required to run in operational condition with the target exposed to focussed electrons when the operator requires the X-ray beam to be produced.

According to the present invention, there is provided an X-ray generator comprising an electron gun, electron focussing means, a target and electronic control means, wherein the area of the target on which the focussing means causes electrons from said electron gun to impinge comprises an X-ray source, the control means being adapted to control the electron focussing means so that the X-ray source on said target may be varied in size and/or shape and/or position.

According to a first aspect of the invention the control means includes a switching means to switch the electron focussing means between a first unfocussed state in which the X-ray source has a first area and a second focussed state in which the X-ray source has a second area smaller than said first area. The second area may be a line, a spot or some other profile. The first area may be a line of greater thickness, a spot of greater diameter or some other shape.

Preferably said first area has a surface area at least twice, more preferably four times, most preferably ten times that of said second area.

According to a second aspect of the invention the control means includes a switching means to switch the electron focussing means between a plurality of focussed states, whereby in each state the X-ray source is in a corresponding discrete position on said target. The X-ray source may be in the form of a line, a spot or some other profile on the target.

The electron gun may comprise an evacuated tube around which the electron focussing means is mounted outside the vacuum. Alternatively the electron gun may comprise an evacuated tube within which the electron focussing means is mounted. The evacuated tube may be a sealed vacuum tube or may be connected to a vacuum pump which permits continuous evacuation during operation of the generator.

The electron focussing means may comprise an x-y deflection system for [centring] centering the electron beam in the tube. The electron beam focussing means may further comprise at least one electron lens, preferably an axially symmetric or round lens, and/or at least one [quadrupole] quadripole or multipole lens for focussing the electron beam to a line focus and for steering the electron beam.

The electron beam lenses may be magnetic or electrostatic.

Preferably the target is metal, most preferably a metal selected from the group Cu, Ag, Mo, Rh, Al, Ti, Cr, Co, Fe, W, Au. The target surface may be orientated such that the plane of the target surface is perpendicular or at an angle to the axis of the X-ray tube.

According to a third aspect of the present invention there is also provided a method for extending the life of a target of an X-ray generator, wherein the generator

comprises an electron gun, electron focussing means and a target, the method comprising the steps of:

firing electrons at the target such that the area of the target on which the focussing means causes electrons from said electron gun to impinge comprises an X-ray source,

controlling the electron focussing means to move between a first unfocussed state in which the X-ray source has a first area and a second focussed state in which the X-ray source has a second area smaller than said first area, the intensity of electron impingement in the first state being sufficiently low to reduce target degradation, the intensity of electron impingement in the second state being sufficiently high such that the source produces a predetermined required level of brightness and source size on the target. The source may be a spot, a line or some other profile.

Preferably the electron beam current is substantially the same in the first and second states, while the intensity of the beam per unit area at the target is lower in the first state than in the second state.

According to a fourth aspect of the present invention there is provided a method for extending the life of a target of an X-ray generator, wherein the generator comprises an electron gun, electron focussing means and a target, the method comprising the steps of:

firing electrons at the target such that the area of the target on which the focussing means causes electrons from said electron gun to impinge comprises an X-ray source,

controlling the electron focussing means to move between a plurality of focussed states, whereby in each state the X-ray source is in a corresponding discrete position on said target, such that the intensity per unit area in each discrete position is substantially constant, and such that there is no overlap on the target between the discrete positions corresponding to each focussed state. The source may be a spot, a line or some other profile.

The lack of overlap between the discrete positions on the target means that a fresh area of target is used as a source each time the electron focussing means moves to a new state. The control of the electron focussing means may be manual but is

preferably electronic, so that each discrete position corresponds to a pre-programmed control signal applied to the electron focussing means.

BRIEF DESCRIPTION OF THE DRAWINGS

5 An embodiment of the invention will now be described, by way of example only, with reference to the accompanying figures, where:

Fig. 1 shows a schematic longitudinal section through an X-ray generator according to the invention suitable for use with a close coupled X-ray focussing system (not shown);

10 Fig. 2 shows a schematic arrangement of an X-ray generator in the focussed state;

Fig. 3 shows a schematic arrangement of an X-ray generator in the defocussed state;

15 Fig. 4 shows a schematic arrangement of an X-ray generator with the target in a first focussed position;

Fig. 5 shows a schematic arrangement of an X-ray generator with the target in a second focussed position;

Figs. 6(a) and 6(b) shows schematically a side view and plan view respectively on a sealed tube X-ray generator according to the invention; and

20 Figs. 7(a) and 7(b) shows schematically a side view and front view respectively on a rotating anode X-ray generator according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

25 With reference to Fig. 1, the X-ray generator 1 comprises an evacuated and sealed X-ray tube 2, containing an electron gun 3 and an X-ray target 4. The tube 2 has an exit window 6 through which X-rays are emitted from the target. Although the embodiment illustrated in Fig. 1 has a window 6 in front of the target 4, it is to be understood that the invention is applicable to other embodiments, for example X-ray generators in which the X-rays are emitted behind the target 4. The exit window does
30 not form part of the invention and is not further described.

The tube 2 is contained within a housing 13. The generator 1 also includes a system 7 for focussing and steering the electron beam 8 onto the target 4.

The focussing and steering system is capable of producing a well focussed beam of electrons 8 impinging on the target 4. The electron beam 8 may be focussed into a spot or a line, and the dimensions of the spot and line as well as its position may be changed electronically. In typical X-ray applications a spot focus having a diameter falling in the range 1 to 100 μm , generally 5 μm or larger, may be required. Alternatively a line focus may be achieved whose width falls in the range 0.4 mm to 1.0 mm, and length in the range 5 mm to 15 mm.

The electron beam 8 is produced by an electron gun 3 consisting of a Wehnelt electrode and cathode. The cathode may be a filament of tungsten or alloy, for example tungsten-rhenium, having either a hairpin or a staple shape. Alternatively the cathode may be an indirectly heated activated dispenser cathode, which may be flat or of other geometry, for example a rod with a domed end. The dispenser cathode has the advantage of extended lifetime and increased mechanical strength. With a flat surface the dispenser cathode has the further advantage of requiring only an approximate degree of alignment in the Wehnelt electrode.

Primary focus is achieved by an anode at a suitable distance from the electron gun.

The electron beam 8 from the gun is [centred] centered in the X-ray tube 2 by a [centring] centering coil 14 or set of [quadrupole] quadripole lenses. Alternatively it may be [centred] centered by [multipole] multipole lenses. Alternatively mechanical means may be used to [centre] center the electron beam 8. The [centring] centering lens or coil 14 may be omitted, where the electron gun 3 is such that it produced an electron beam 8 which is sufficiently aligned within the tube 2.

The electron beam 8 is then focussed to a spot of varying diameter. Focussing down to a diameter of less than 5 μm or better may be achieved by an axial focussing lens 15 of the [quadrupole,] quadripole, multipole or solenoid type.

The spot focus may be changed to a line focus with a stigmator lens 16, which may comprise a further set of [quadrupole,] quadripole or multipole lenses. Lines

with an aspect ratio of greater than 10:1 are possible. A line focus spreads the load on the target. When viewed at a suitable angle, the line appears as a spot.

The lenses 15, 16 are preferably magnetic, but may be electrostatic. All the lenses are electronically controlled, enabling remote control and continuous alignment and scanning of the focal spot. Change from spot to line focus and change of beam diameter are also controlled remotely by varying the control signals to the electron focussing devices 7.

The electronic control of the lenses enables the electron beam 8 to be defocussed and/or repositioned on the target 4. As a result, the high intensity focal spot of the electron beam 8 is not continuously being directed at one particular area of the target 4, which means that the rate of degradation of the target will be significantly slower than with known X-ray generators. The electron beam 8 is only focussed at high intensity when the X-ray beam is required.

The actions of defocussing and refocussing the electron beam 8 are activated either at will by the operator by varying the power of the focussing coils, preferably by an electronic switch control, or automatically by the action of a shutter on the output side of the X-ray beam or other external event defined by the operator.

The target 4 is a metal, for example Cu, but it can be another material depending on the wavelength of the characteristic radiation required, for example Ag, Mo, Al, Ti, Rh, Cr, Co, Fe, W or Au. The target 4 is either perpendicular to the impinging electron beam 8, or may be inclined to decrease the absorption of the emitted X-rays.

In an example of a preferred embodiment of the present invention, the cathode is at negative high voltage and the electron gun 3 consists of a filament just inside the aperture 11 of a Wehnelt grid which is biased negatively with respect to the filament. The electrons are accelerated towards the anode which is at ground potential and pass through a hole in the latter and then through the tube 2 towards the target 4. Two sets of beam deflection coils 14, which may be iron-cored, are employed in two planes separated by 30 mm, mounted between the anode of the electron gun 3 and the focussing lens 15 to [centre] center the beam. Between the focussing lens 15 and the target 4 is an air-cored [quadrupole] quadripole magnet which acts as a stigmator 16 in

that it turns the circular cross-section of the beam 8 into an elongated one. This [quadrupole] quadrupole 16 can be rotated about the tube axis so as to adjust the orientation of the line focus. The beam 8 can be moved about on the target surface 4 by controlling the currents in the four coils of the [quadrupole] quadrupole 16.

5 With reference to Figs. 2 and 3 there is shown a tube 2, electron gun 3 and target 4, together with electron focussing means 7, which are discussed in more detail above. In the first focussed state, as shown in Fig. 2, the electron beam 8 is focussed by the focussing means 7 so that it forms a relatively small spot 20 on the target 4, the spot source being the required size for generation of X-rays for the intended purpose.

10 In this state the X-ray generator is operational and the brightness of the emitted X-ray beam may be controlled by varying the applied power to the tube. When the generator is switched to the second unfocussed state as shown in Fig. 3, the electron beam 18 has the same power, but the focussing means does not focus the beam 18 so tightly, so that it forms a relatively larger spot source 21 on the target 4. In this state the X-ray

15 generator is in standby mode and the intensity per unit area at the target 4 is greatly reduced. The consequent [localised] localized degradation of the target, which depends on local intensity per unit area, is also reduced.

With reference to Figs. 4 and 5 there is shown a tube 2, electron gun 3 and target 4, together with electron focussing means 7, which are discussed in more detail

20 above. In the first focussed state, as shown in Fig. 4, the electron beam 28 is focussed by the focussing means 7 so that it forms a relatively small spot source 22 on the target 4, the spot source being the required size for generation of X-rays for the intended purpose. In this state the X-ray generator is operational and the brightness of the emitted X-ray beam may be controlled by varying the applied power to the tube.

25 When the generator is switched to a second focussed state, as shown in Fig. 5, the electron beam 38 has the same power, but is focussed by the focussing means to a second spot source 23 on a different part of the target 4. The spot source 23 is the required size for generation of X-rays for the intended purpose, and will generally be the same size as the spot source 22 in the first state. There is no overlap between the

30 positions of spot sources 22 and 23.

used to change the shape and/or size of the beam. A switch control (not shown) may be provided which upon operation automatically provides the electrical power to the coils 34 so as to steer the electron beam to a larger focus or to a different point on the target. This enables the power density loading on the target 32 to be reduced when the X-rays are not being used, or for new areas of the target 32 to be periodically exposed when the previously exposed area becomes damaged or degraded. In Fig. 6 the coils 34 are shown as being external to the vacuum. In this way it is possible for the focussing coils 34 to be retrofitted to an existing generator, in order to prolong the life of the generator. However the scope of the invention includes the case where the coils 34 are built in to the generator and provided inside the vacuum enclosure 30.

Figs. 7(a) and 7(b) shows schematically a side view and front view respectively on a conventional rotating anode X-ray generator. The generator comprises a continuously pumped vacuum chamber 40 containing an electron gun 41 and a target 42 deposited on a cylindrical anode 43 which rotates at high speed. Adjacent to the anode are X-ray transparent windows 44, through which X-rays 46 are transmitted. Surrounding the vacuum chamber between the electron gun 41 and target 42 is an electrostatic or electromagnetic lens. The anode 43 is water cooled (not shown). The rotation of the anode 43 dissipates more effectively the heat generated on the target 42, so that increased power loading of the target and hence increased X-ray brightness are possible.

The electrostatic or electromagnetic lens comprises one or more sets of focussing coils 45 arranged outside the vacuum chamber 40. The coils 45 serve the same purpose as the coils 34 described with reference to Fig. 6 above, and may also be retrofitted or fitted within the vacuum chamber, [ie] i.e., the coils may be internal or external.

These and other modifications and improvements can be incorporated without departing from the scope of the invention.

CLAIMS

1. An x-ray generator comprising an electron gun, electron focusing
5 means, a target and electronic control means, wherein [the] an area of the target on
which the focusing means causes electrons from said electron gun to impinge
comprises an x-ray source emitting an x-ray beam, the control means being adapted to
control the electron focusing means so that the x-ray source on said target may be
varied in size, wherein the x-ray generator further comprises a shutter to control the
10 emitted x-ray beam, and wherein the control means includes a switching means to
switch the electron focusing means between a first unfocused state in which the x-ray
source has a first area upon action of the shutter and a second focused state in which
the x-ray source has a second area smaller than said first area when the shutter is open.

15 2. [An] The x-ray generator according to Claim 1, wherein said first area
has a surface area at least twice that of said second area.

20 3. [An] The x-ray generator according to Claim 1, wherein said first area
has a surface area at least four times that of said second area.

4. [An] The x-ray generator according to Claim 1, wherein said first area
has a surface area at least ten times that of said second area.

25 5. An x-ray generator comprising an electron gun, electron focusing
means, a target and electronic control means, wherein the area of the target on which
the focusing means causes electrons from said electron gun to impinge comprises an
x-ray source generating an x-ray beam output, the control means being adapted to
control the electron focusing means so that the x-ray source on said target may be
varied in size, wherein the control means includes a switching means to switch the
30 electron focusing means between a plurality of focused states, whereby in each state
the x-ray source is in a corresponding discrete stationary position on said target.

6. [An] The x-ray generator according to [any preceding] Claim 5, wherein the electron gun comprises an evacuated tube, and wherein the electron focusing means comprises an x-y deflection system for [centring] centering the electron beam in the tube.

7. [An] The x-ray generator according to [any preceding] Claim 6, wherein the electron beam focusing means further comprises at least one electron lens.

8. [An] The x-ray generator according to Claim 7, wherein said electronic lens comprises an axially symmetric or round lens for focusing the electron beam to a line focus and for steering the electron beam.

9. [An] The x-ray generator according to Claim 7, wherein said electron lens comprises at least one [quadrupole] quadripole or multipole lens for focusing the electron beam to a line focus and for steering the electron beam.

10. [An] The x-ray generator according to [any preceding] Claim 5, wherein the target is a metal selected from the group Cu, Ag, Mo, Rh, Al, Ti, Cr, Co, Fe, W, Au.

11. A method for extending the life of a target of an x-ray generator, wherein the generator comprises an electron gun, electron focusing means and a target, the method comprising the steps of:

firing electrons at the target such that the area of the target on which the focusing means causes electrons from said electron gun to impinge comprises an x-ray source emitting an x-ray beam,

controlling the emitted x-ray beam by action of a shutter in its path, and

controlling the electron focusing means by the action of the shutter to move between a first unfocused state in which the x-ray source has a first area and a second focused state in which the x-ray source has a second area smaller than said first area,

the intensity of electron impingement in the first state being sufficiently low to reduce target degradation, the intensity of electron impingement in the second state being sufficiently high such that the source produces a predetermined required level of brightness and source size on the target.

5

12. [A] The method according to Claim 11, wherein the electron beam current is substantially the same in the first and second states, while the intensity of the beam per unit area at the target is lower in the first state than in the second state.

10

13. A method of extending the life of a target of an x-ray generator, wherein the generator comprises an electron gun, electron focusing means and a target, the method comprising the steps of:

15

firing electrons at the target such that the area of the target on which the focusing means causes electrons from said electron gun to impinge comprises an x-ray source, and

20

controlling the electron focusing means to move between a plurality of focused states, whereby in each state the x-ray source is in a corresponding discrete stationary position on said target, such that the intensity per unit area in each discrete position is substantially constant, and such that there is no overlap on the target between the discrete positions corresponding to each focused state.

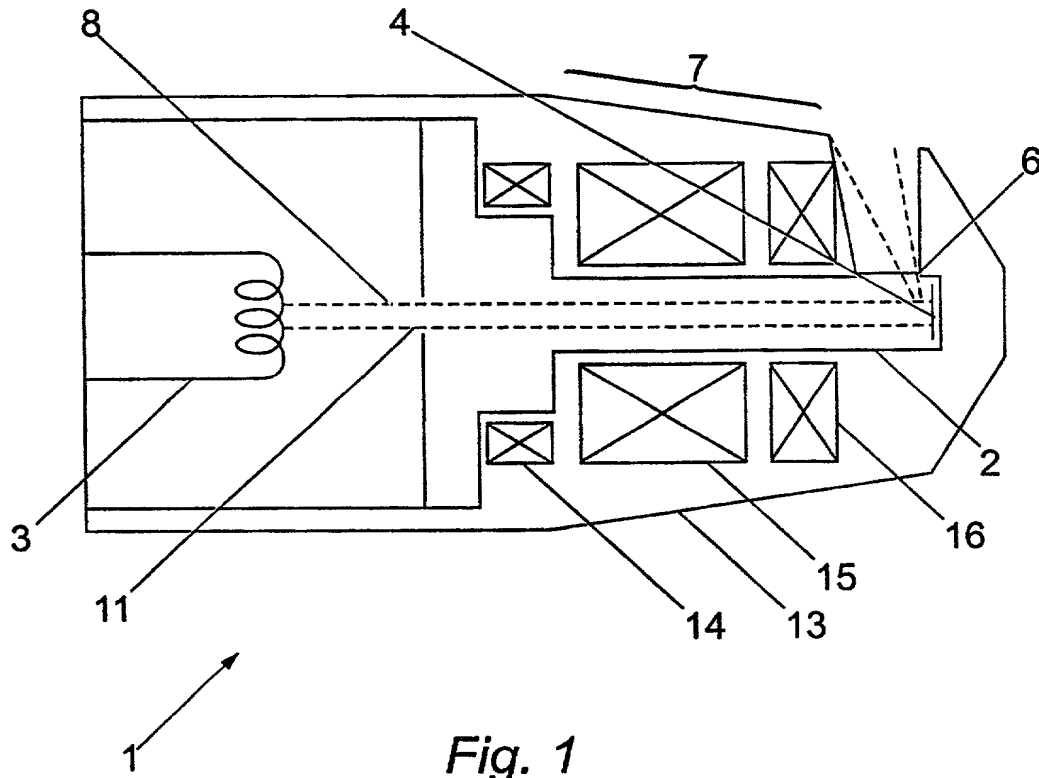


Fig. 1

Fig. 2

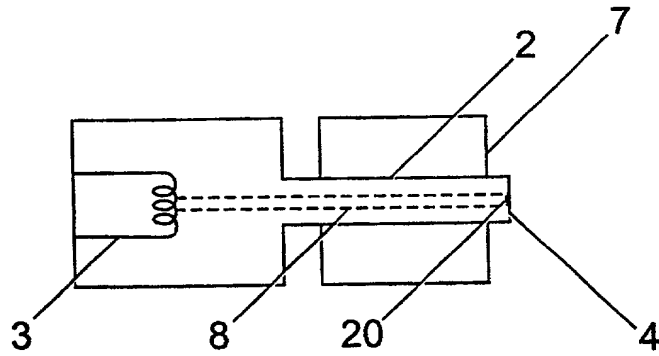


Fig. 3

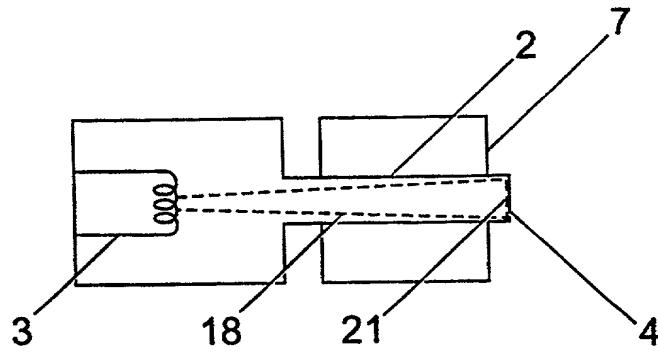


Fig. 4

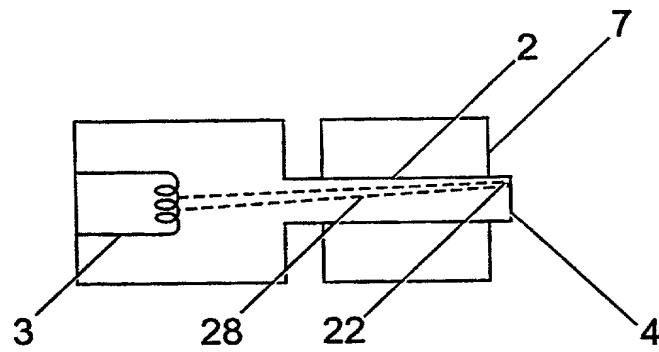
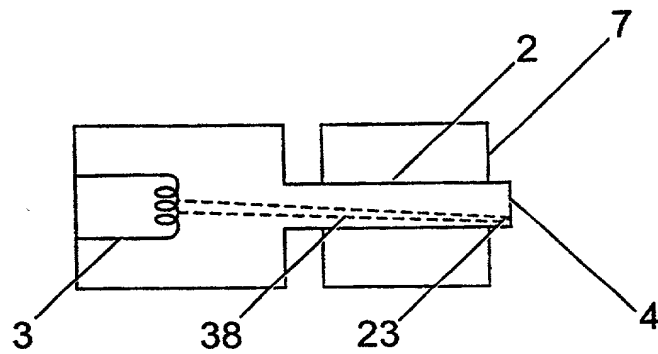


Fig. 5



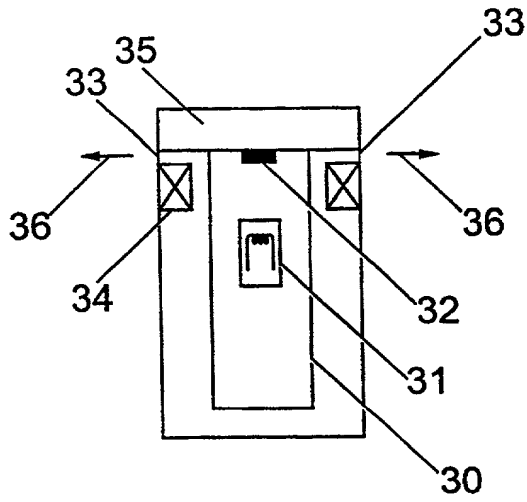


Fig. 6a

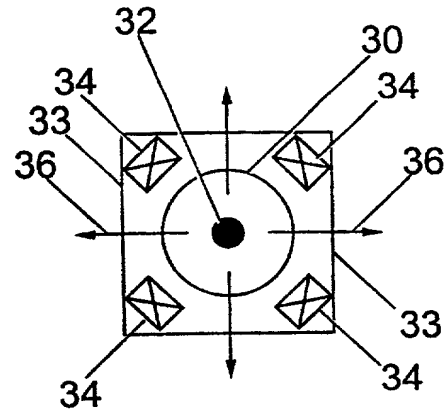


Fig. 6b

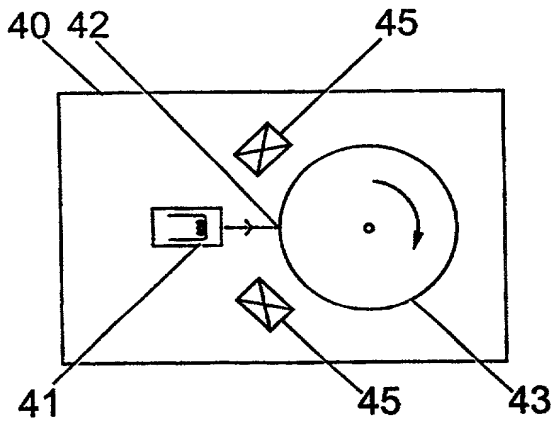


Fig. 7a

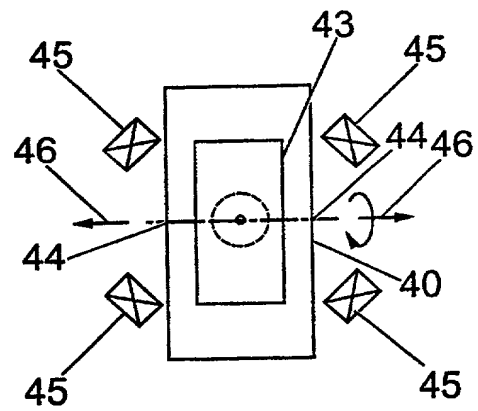


Fig. 7b

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1 Method and Apparatus for Prolonging the Life of an
2 X-Ray Target
3

4 This invention relates to an X-ray generator, and in
5 particular to apparatus for prolonging the life of an
6 X-ray target used within an X-ray generator.
7

8 Known X-ray generators comprise an electron gun, an X-
9 ray target and an X-ray exit window. These generators
10 produce X-rays by accelerating electrons from the
11 electron gun into the x-ray target. X-rays are emitted
12 from the target through the exit window. Such
13 generators may be in the form of sealed X-ray tubes,
14 for example microfocus tubes, which are evacuated once
15 and then sealed off, or in the form of rotating anode
16 generators, which are permanently connected to vacuum
17 pumps and are continuously evacuated during operation.
18

19 A major limitation to the longevity of X-ray generators
20 is the lifetime of the target. All targets degrade
21 over time due to the effects of heat and roughening
22 caused by the electron bombardment. There are various
23 known methods for reducing these effects, including
24 cooling the back of the target with flowing water or
25 rotating the target so that no one area of the target
26 is continuously subjected to the electron bombardment.

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1 Methods of increasing the cooling efficiency have been
2 proposed based on using high conductivity materials
3 such as diamonds. However, these methods are not in
4 common usage currently.

5
6 With known X-ray generators, it can take a number of
7 minutes after switching on the machine before it has
8 stabilised and is ready for use. As a result, many
9 generators are simply left running throughout the day,
10 so that the "warm-up" or stabilisation delay is
11 removed. This means that the electrons are focussed on
12 the target for long periods of time during each use of
13 the generator, which leads to accelerated degradation
14 of the target, even though the radiation produced by
15 the X-ray generator is used only for short periods.

16
17 In cases where the construction of the generator
18 permits, the target can be replaced. Where the
19 construction does not permit target replacement in a
20 routine procedure, then it is common practice to
21 discard the complete tube assembly making up the X-ray
22 generator.

23
24 In commercially available sealed tube and rotating
25 anode generators, there is no provision to control the
26 position of the beam on the target or to control the
27 quality, size or shape of the focal spot on the X-ray
28 target. The quality of the X-ray beam emitted can
29 deteriorate rapidly with prolonged use due to
30 contamination and damage to the target area under
31 continuous electron bombardment.

32
33 In the case of rotating anode generators, once
34 performance has degraded below a useful level,
35 replacement of the target is required. This entails
36 cost of replacement parts as well as significant down

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1 time of the generator. In the case of sealed tube
2 generators it is necessary to discard the whole tube and
3 replace it with a new tube.

4
5 It is an object of the present invention to provide
6 means to lengthen the life of a target, and thereby to
7 lengthen the life of the X-ray generator. By
8 controlling the position and brightness of the beam,
9 the apparatus according to the present invention can
10 reposition and modify the area of focus of the beam.
11 Defocussing the beam reduces the flux per unit area of
12 electrons on the target. Repositioning the beam
13 enables a fresh area of the target to be exposed to
14 electrons. The lifespan of the target is prolonged by
15 either of these means, and the time interval between
16 replacements of the target or of the complete tube
17 assembly is increased.

18
19 A consequence of the approach of the present invention
20 is that the tube is only required to run in operational
21 condition with the target exposed to focussed electrons
22 when the operator requires the X-ray beam to be
23 produced.

24
25 According to the present invention, there is provided
26 an X-ray generator comprising an electron gun, electron
27 focussing means, a target and electronic control means,
28 wherein the area of the target on which the focussing
29 means causes electrons from said electron gun to
30 impinge comprises an X-ray source, the control means
31 being adapted to control the electron focussing means
32 so that the X-ray source on said target may be varied
33 in size and/or shape and/or position.

34
35 According to a first aspect of the invention the
36 control means includes a switching means to switch the

1 electron focussing means between a first unfocussed
2 state in which the X-ray source has a first area and a
3 second focussed state in which the X-ray source has a
4 second area smaller than said first area. The second
5 area may be a line, a spot or some other profile. The
6 first area may be a line of greater thickness, a spot
7 of greater diameter or some other shape.

8

9 Preferably said first area has a surface area at least
10 twice, more preferably four times, most preferably ten
11 times that of said second area.

12

13 According to a second aspect of the invention the
14 control means includes a switching means to switch the
15 electron focussing means between a plurality of
16 focussed states, whereby in each state the X-ray source
17 is in a corresponding discrete position on said target.
18 The X-ray source may be in the form of a line, a spot
19 or some other profile on the target.

20

21 The electron gun may comprise an evacuated tube around
22 which the electron focussing means is mounted outside
23 the vacuum. Alternatively the electron gun may
24 comprise an evacuated tube within which the electron
25 focussing means is mounted. The evacuated tube may be
26 a sealed vacuum tube or may be connected to a vacuum
27 pump which permits continuous evacuation during
28 operation of the generator.

29

30 The electron focussing means may comprise an x-y
31 deflection system for centring the electron beam in the
32 tube. The electron beam focussing means may further
33 comprise at least one electron lens, preferably an
34 axially symmetric or round lens, and/or at least one
35 quadrupole or multipole lens for focussing the electron
36 beam to a line focus and for steering the electron

1 According to a fourth aspect of the present invention
2 there is provided a method for extending the life of a
3 target of an X-ray generator, wherein the generator
4 comprises an electron gun, electron focussing means and
5 a target, the method comprising the steps of:
6 firing electrons at the target such that the area of
7 the target on which the focussing means causes
8 electrons from said electron gun to impinge comprises
9 an X-ray source,
10 controlling the electron focussing means to move
11 between a plurality of focussed states, whereby in
12 each state the X-ray source is in a corresponding
13 discrete position on said target, such that the
14 intensity per unit area in each discrete position is
15 substantially constant, and such that there is no
16 overlap on the target between the discrete positions
17 corresponding to each focussed state. The source may
18 be a spot, a line or some other profile.

19
20 The lack of overlap between the discrete positions on
21 the target means that a fresh area of target is used as
22 a source each time the electron focussing means moves
23 to a new state. The control of the electron focussing
24 means may be manual but is preferably electronic, so
25 that each discrete position corresponds to a pre-
26 programmed control signal applied to the electron
27 focussing means.

28
29 An embodiment of the invention will now be described,
30 by way of example only, with reference to the
31 accompanying figures, where:

32
33 Fig. 1 shows a schematic longitudinal section through
34 an X-ray generator according to the invention suitable
35 for use with a close coupled X-ray focussing system
36 (not shown);

1

2 Fig. 2 shows a schematic arrangement of an X-ray
3 generator in the focussed state;

4

5 Fig. 3 shows a schematic arrangement of an X-ray
6 generator in the defocussed state;

7

8 Fig. 4 shows a schematic arrangement of an X-ray
9 generator with the target in a first focussed position;

10

11 Fig. 5 shows a schematic arrangement of an X-ray
12 generator with the target in a second focussed
13 position;

14

15 Figs. 6(a) and 6(b) shows schematically a side view and
16 plan view respectively on a sealed tube X-ray generator
17 according to the invention; and

18

19 Figs. 7(a) and 7(b) shows schematically a side view and
20 front view respectively on a rotating anode X-ray
21 generator according to the invention.

22

23 With reference to Fig. 1, the X-ray generator 1
24 comprises an evacuated and sealed X-ray tube 2,
25 containing an electron gun 3 and an X-ray target 4.
26 The tube 2 has an exit window 6 through which X-rays
27 are emitted from the target. Although the embodiment
28 illustrated in Fig. 1 has a window 6 in front of the
29 target 4, it is to be understood that the invention is
30 applicable to other embodiments, for example X-ray
31 generators in which the X-rays are emitted behind the
32 target 4. The exit window does not form part of the
33 invention and is not further described.

34

35 The tube 2 is contained within a housing 13. The
36 generator 1 also includes a system 7 for focussing and

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The electron beam 8 from the gun is centred in the X-ray tube 2 by a centring coil 14 or set of quadrupole lenses. Alternatively it may be centred by multipole lenses. Alternatively mechanical means may be used to centre the electron beam 8. The centring lens or coil

14 may be omitted, where the electron gun 3 is such that it produced an electron beam 8 which is sufficiently aligned within the tube 2.

The electron beam 8 is then focussed to a spot of varying diameter. Focussing down to a diameter of less than 5 μm or better may be achieved by an axial focussing lens 15 of the quadrupole, multipole or solenoid type.

The spot focus may be changed to a line focus with a stigmator lens 16, which may comprise a further set of quadrupole or multipole lenses. Lines with an aspect ratio of greater than 10:1 are possible. A line focus spreads the load on the target. When viewed at a suitable angle, the line appears as a spot.

The lenses 15, 16 are preferably magnetic, but may be electrostatic. All the lenses are electronically controlled, enabling remote control and continuous alignment and scanning of the focal spot. Change from spot to line focus and change of beam diameter are also controlled remotely by varying the control signals to the electron focussing devices 7.

The electronic control of the lenses enables the electron beam 8 to be defocussed and/or repositioned on the target 4. As a result, the high intensity focal spot of the electron beam 8 is not continuously being directed at one particular area of the target 4, which means that the rate of degradation of the target will be significantly slower than with known X-ray generators. The electron beam 8 is only focussed at high intensity when the X-ray beam is required.

The actions of defocussing and refocussing the electron

1 beam 8 are activated either at will by the operator by
2 varying the power of the focussing coils, preferably by
3 an electronic switch control, or automatically by the
4 action of a shutter on the output side of the X-ray
5 beam or other external event defined by the operator.

6
7 The target 4 is a metal, for example Cu, but it can be
8 another material depending on the wavelength of the
9 characteristic radiation required, for example Ag, Mo,
10 Al, Ti, Rh, Cr, Co, Fe, W or Au. The target 4 is
11 either perpendicular to the impinging electron beam 8,
12 or may be inclined to decrease the absorption of the
13 emitted X-rays.

14
15 In an example of a preferred embodiment of the present
16 invention, the cathode is at negative high voltage and
17 the electron gun 3 consists of a filament just inside
18 the aperture 11 of a Wehnelt grid which is biased
19 negatively with respect to the filament. The electrons
20 are accelerated towards the anode which is at ground
21 potential and pass through a hole in the latter and
22 then through the tube 2 towards the target 4. Two sets
23 of beam deflection coils 14, which may be iron-cored,
24 are employed in two planes separated by 30 mm, mounted
25 between the anode of the electron gun 3 and the
26 focussing lens 15 to centre the beam. Between the
27 focussing lens 15 and the target 4 is an air-cored
28 quadrupole magnet which acts as a stigmator 16 in that
29 it turns the circular cross-section of the beam 8 into
30 an elongated one. This quadrupole 16 can be rotated
31 about the tube axis so as to adjust the orientation of
32 the line focus. The beam 8 can be moved about on the
33 target surface 4 by controlling the currents in the
34 four coils of the quadrupole 16.

35
36 With reference to Figs. 2 and 3 there is shown a tube

2, electron gun 3 and target 4, together with electron focussing means 7, which are discussed in more detail above. In the first focussed state, as shown in Fig. 2, the electron beam 8 is focussed by the focussing means 7 so that it forms a relatively small spot 20 on the target 4, the spot source being the required size for generation of X-rays for the intended purpose. In this state the X-ray generator is operational and the brightness of the emitted X-ray beam may be controlled by varying the applied power to the tube. When the generator is switched to the second unfocussed state as shown in Fig. 3, the electron beam 18 has the same power, but the focussing means does not focus the beam 18 so tightly, so that it forms a relatively larger spot source 21 on the target 4. In this state the X-ray generator is in standby mode and the intensity per unit area at the target 4 is greatly reduced. The consequent localised degradation of the target, which depends on local intensity per unit area, is also reduced.

With reference to Figs. 4 and 5 there is shown a tube 2, electron gun 3 and target 4, together with electron focussing means 7, which are discussed in more detail above. In the first focussed state, as shown in Fig. 4, the electron beam 28 is focussed by the focussing means 7 so that it forms a relatively small spot source 22 on the target 4, the spot source being the required size for generation of X-rays for the intended purpose. In this state the X-ray generator is operational and the brightness of the emitted X-ray beam may be controlled by varying the applied power to the tube. When the generator is switched to a second focussed state, as shown in Fig. 5, the electron beam 38 has the same power, but is focussed by the focussing means to a second spot source 23 on a different part of the target

1 4. The spot source 23 is the required size for
2 generation of X-rays for the intended purpose, and will
3 generally be the same size as the spot source 22 in the
4 first state. There is no overlap between the positions
5 of spot sources 22 and 23.

6
7 In practice there may be further operational states in
8 which the spot source is the same size as spot sources
9 22, 23 but in different, non-overlapping locations. It
10 may be possible to fit as many as ten or more non-
11 overlapping sources on a target, thus giving a ten-fold
12 increase in the life of the target. The focussing
13 means 7 may be adjusted manually to move the spot
14 source, or the control signals required to adjust the
15 focussing means may be stored electronically, so that
16 the apparatus automatically steps to the next state
17 when an operator indicates that the position of the
18 focus should be changed. The stepping could be
19 automatic after a predetermined elapsed operating time
20 at a particular state, for example an elapsed time
21 counter could be built into the apparatus to show a
22 warning signal when the predetermined operating time is
23 exceeded. The operator would then be alerted to switch
24 the apparatus to the next state.

25
26 Although the examples of Figs. 2 to 5 have been
27 described with reference to spot sources, it is to be
28 understood that the invention is equally applicable to
29 line focus sources. Furthermore the illustrated
30 embodiments have been described with a focussing means
31 which comprises a centring lens, a focussing lens and a
32 stigmator lens. It is to be understood that the
33 functions of any of the three lenses may be combined in
34 one or more lenses, and that the order of the
35 components of the focussing means may be varied.

36

1 Figs. 6(a) and 6(b) shows schematically a side view and
2 plan view respectively on a conventional sealed tube X-
3 ray generator. The generator comprises a sealed vacuum
4 enclosure 30 fabricated from glass and metal, or from
5 ceramic and metal. Inside the enclosure 30 is an
6 electron gun 31 and a target 32. Adjacent to the
7 target are X-ray transparent windows 33, through which
8 X-rays 36 are transmitted. Surrounding the vacuum
9 enclosure between the electron gun 31 and target 32 is
10 an electrostatic or electromagnetic lens. Behind the
11 target is a conventional water cooling arrangement 35.
12

13 The lens comprises one or more sets of focussing coils
14 34 arranged outside the vacuum envelope of the X-ray
15 tube 30. The coils 34 forming the lens may be
16 electromagnetic or electrostatic. At least one of the
17 sets of focussing coils 34 is used to steer the
18 electron beam from the electron gun 31 onto the target
19 32, and may also be used to change the shape and/or
20 size of the beam. A switch control (not shown) may be
21 provided which upon operation automatically provides
22 the electrical power to the coils 34 so as to steer the
23 electron beam to a larger focus or to a different point
24 on the target. This enables the power density loading
25 on the target 32 to be reduced when the X-rays are not
26 being used, or for new areas of the target 32 to be
27 periodically exposed when the previously exposed area
28 becomes damaged or degraded. In Fig. 6 the coils 34
29 are shown as being external to the vacuum. In this way
30 it is possible for the focussing coils 34 to be
31 retrofitted to an existing generator, in order to
32 prolong the life of the generator. However the scope
33 of the invention includes the case where the coils 34
34 are built in to the generator and provided inside the
35 vacuum enclosure 30.
36

1 Figs. 7(a) and 7(b) shows schematically a side view and
2 front view respectively on a conventional rotating
3 anode X-ray generator. The generator comprises a
4 continuously pumped vacuum chamber 40 containing an
5 electron gun 41 and a target 42 deposited on a
6 cylindrical anode 43 which rotates at high speed.
7 Adjacent to the anode are X-ray transparent windows 44,
8 through which X-rays 46 are transmitted. Surrounding
9 the vacuum chamber between the electron gun 41 and
10 target 42 is an electrostatic or electromagnetic lens.
11 The anode 43 is water cooled (not shown). The rotation
12 of the anode 43 dissipates more effectively the heat
13 generated on the target 42, so that increased power
14 loading of the target and hence increased X-ray
15 brightness are possible.

16
17 The electrostatic or electromagnetic lens comprises one
18 or more sets of focussing coils 45 arranged outside the
19 vacuum chamber 40. The coils 45 serve the same purpose
20 as the coils 34 described with reference to Fig. 6
21 above, and may also be retrofitted or fitted within the
22 vacuum chamber, ie the coils may be internal or
23 external.

24
25 These and other modifications and improvements can be
26 incorporated without departing from the scope of the
27 invention.
28

1 CLAIMS

2

3 1. An x-ray generator comprising an electron gun,
4 electron focusing means, a target and electronic
5 control means, wherein the area of the target on
6 which the focusing means causes electrons from said
7 electron gun to impinge comprises an x-ray source
8 emitting an x-ray beam, the control means being
9 adapted to control the electron focusing means so
10 that the x-ray source on said target may be varied
11 in size, wherein the x-ray generator further
12 comprises a shutter to control the emitted x-ray
13 beam, and wherein the control means includes a
14 switching means to switch the electron focusing
15 means between a first unfocused state in which the
16 x-ray source has a first area upon action of the
17 shutter and a second focused state in which the x-
18 ray source has a second area smaller than said first
19 area when the shutter is open.

20

21 2. An x-ray generator according to Claim 1,
22 wherein said first area has a surface area at least
23 twice that of said second area.

24

25 3. An x-ray generator according to Claim 1,
26 wherein said first area has a surface area at least
27 four times that of said second area.

28

29 4. An x-ray generator according to Claim 1,
30 wherein said first area has a surface area at least
31 ten times that of said second area.

32

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1 5. An x-ray generator comprising an electron gun,
2 electron focusing means, a target and electronic
3 control means, wherein the area of the target on
4 which the focusing means causes electrons from said
5 electron gun to impinge comprises an x-ray source
6 generating an x-ray beam output, the control means
7 being adapted to control the electron focusing means
8 so that the x-ray source on said target may be
9 varied in size, wherein the control means includes a
10 switching means to switch the electron focusing
11 means between a plurality of focused states, whereby
12 in each state the x-ray source is in a corresponding
13 discrete stationary position on said target.

14
15 6. An x-ray generator according to any preceding
16 Claim, wherein the electron gun comprises an
17 evacuated tube, and wherein the electron focusing
18 means comprises an x-y deflection system for
19 centring the electron beam in the tube.

20
21 7. An x-ray generator according to any preceding
22 Claim, wherein the electron beam focusing means
23 further comprises at least one electron lens.

24
25 8. An x-ray generator according to Claim 7,
26 wherein said electronic lens comprises an axially
27 symmetric or round lens for focusing the electron
28 beam to a line focus and for steering the electron
29 beam.

30
31 9. An x-ray generator according to Claim 7,
32 wherein said electron lens comprises at least one

1 quadrupole or multipole lens for focusing the
2 electron beam to a line focus and for steering the
3 electron beam.

4
5 10. An x-ray generator according to any preceding
6 Claim, wherein the target is a metal selected from
7 the group Cu, Ag, Mo, Rh, Al, Ti, Cr, Co, Fe, W, Au.

8
9 11. A method for extending the life of a target of
10 an x-ray generator, wherein the generator comprises
11 an electron gun, electron focusing means and a
12 target, the method comprising the steps of:
13 firing electrons at the target such that the
14 area of the target on which the focusing means
15 causes electrons from said electron gun to impinge
16 comprises an x-ray source emitting an x-ray beam,
17 controlling the emitted x-ray beam by action of
18 a shutter in its path, and
19 controlling the electron focusing means by the
20 action of the shutter to move between a first
21 unfocused state in which the x-ray source has a
22 first area and a second focused state in which the
23 x-ray source has a second area smaller than said
24 first area, the intensity of electron impingement in
25 the first state being sufficiently low to reduce
26 target degradation, the intensity of electron
27 impingement in the second state being sufficiently
28 high such that the source produces a predetermined
29 required level of brightness and source size on the
30 target.

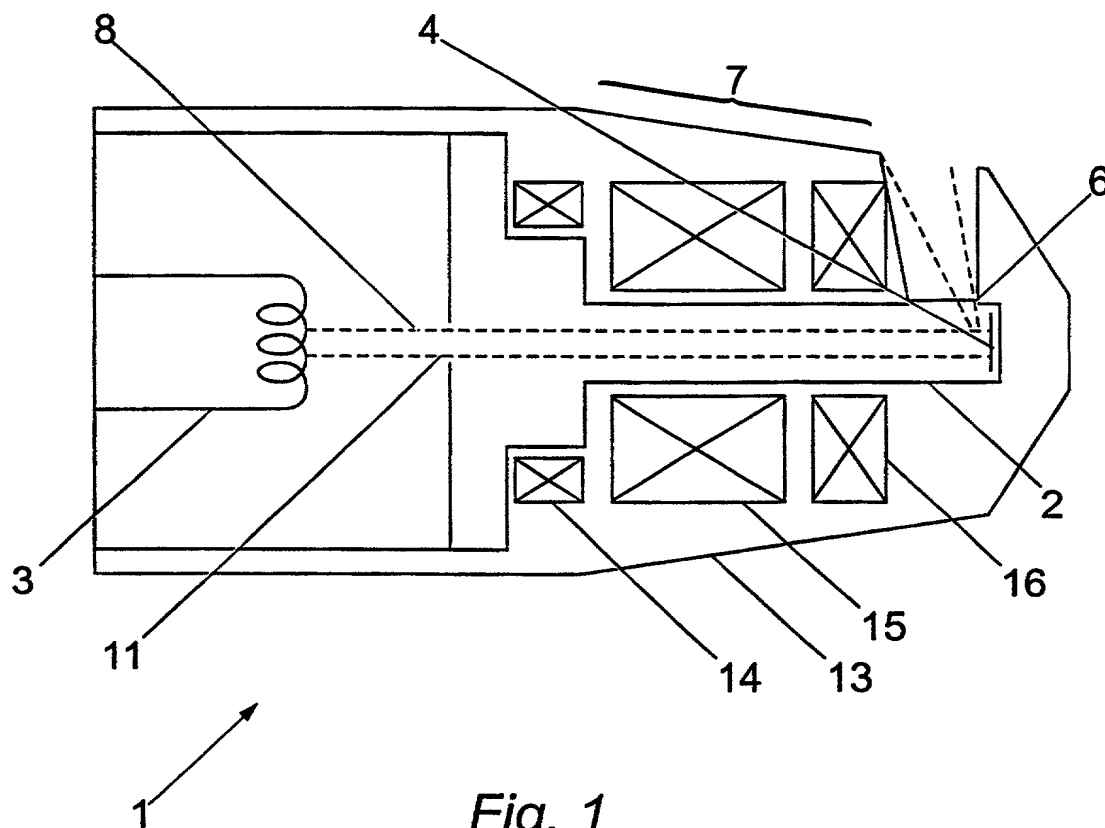
31

1 12. A method according to Claim 11, wherein the
2 electron beam current is substantially the same in
3 the first and second states, while the intensity of
4 the beam per unit area at the target is lower in the
5 first state than in the second state.
6

7 13. A method of extending the life of a target of
8 an x-ray generator, wherein the generator comprises
9 an electron gun, electron focusing means and a
10 target, the method comprising the steps of:

11 firing electrons at the target such that the
12 area of the target on which the focusing means
13 causes electrons from said electron gun to impinge
14 comprises an x-ray source, and

15 controlling the electron focusing means to move
16 between a plurality of focused states, whereby in
17 each state the x-ray source is in a corresponding
18 discrete stationary position on said target, such
19 that the intensity per unit area in each discrete
20 position is substantially constant, and such that
21 there is no overlap on the target between the
22 discrete positions corresponding to each focused
23 state.



2 / 3

Fig. 2

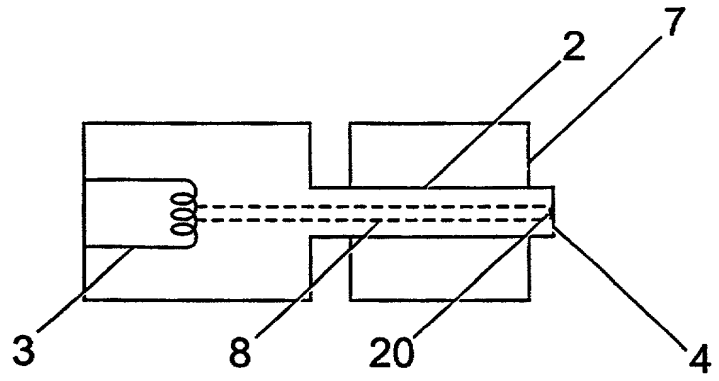


Fig. 3

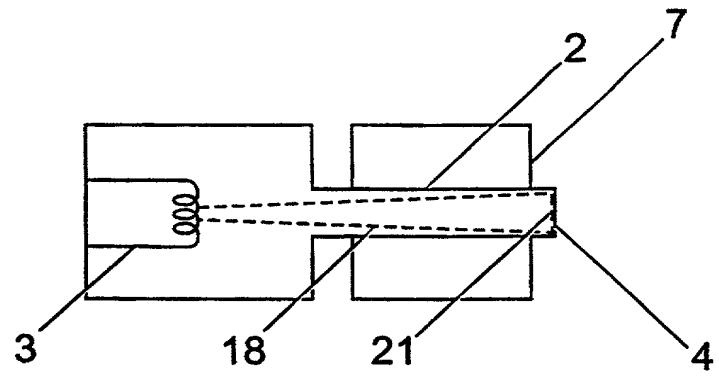


Fig. 4

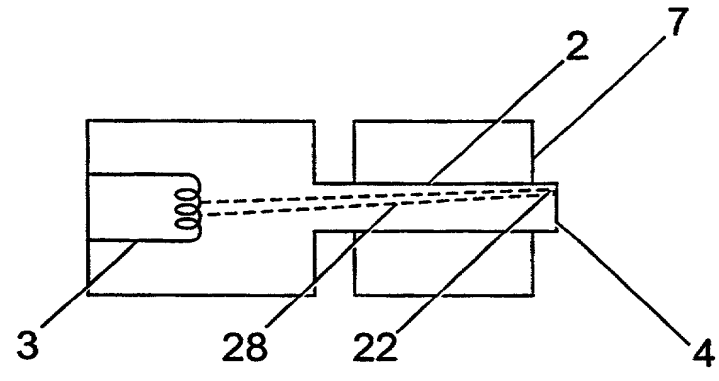
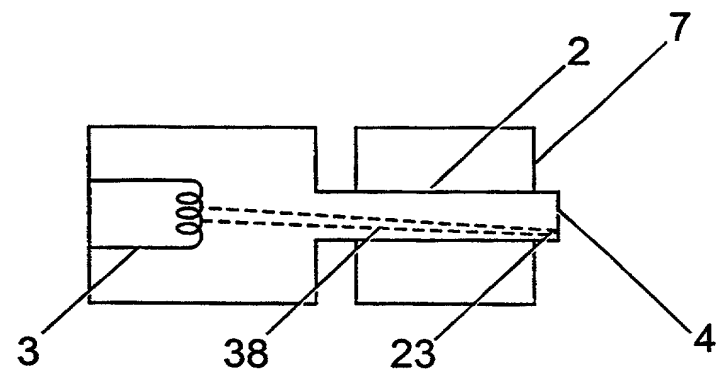


Fig. 5



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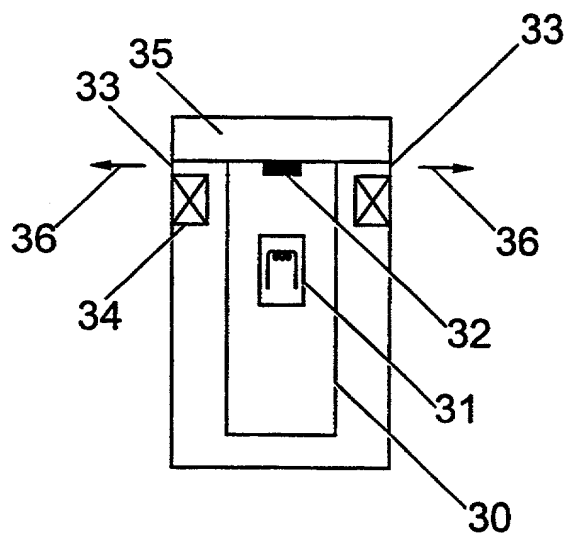


Fig. 6a

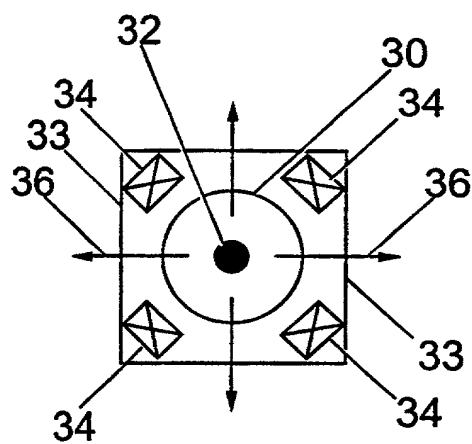


Fig. 6b

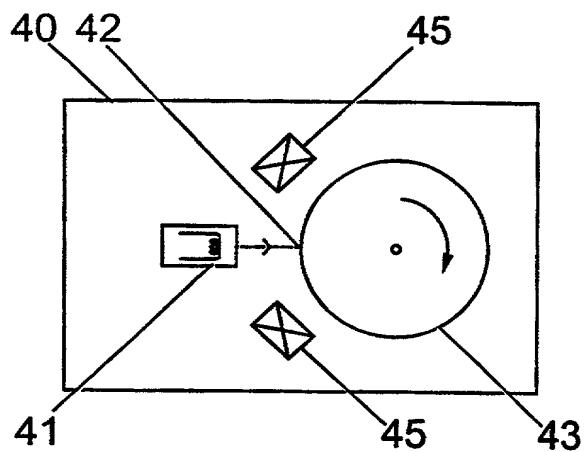


Fig. 7a

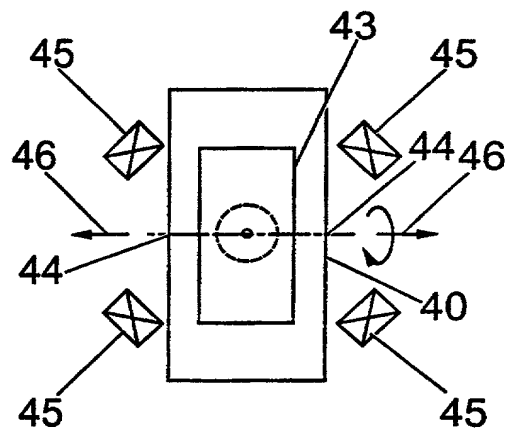


Fig. 7b

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	First Named Inventor	Loxley, Neil
	COMPLETE IF KNOWN	
	Application Number	09/937,609
	Filing Date	Unknown
	Group Art Unit	Unknown
	Examiner Name	Unknown

As a below named inventor, I hereby declare that:

My residence, mailing address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

METHOD AND APPARATUS FOR PROLONGING THE LIFE OF AN X-RAY TARGET

(Title of the Invention)

the specification of which

☐ is attached hereto

OR

☒ was filed on (MM/DD/YY)

09/26/01

as United States Application Number or PCT International (if applicable).

Application Number

09/937,609

and was amended on (MM/DD/YY)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims as amended by any amendment specifically referred to above.

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I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority		Certified Copy Attached?	
			Not claimed		YES	NO
PCT/GB00/01164		03/27/00	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

I hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)	<input type="checkbox"/> Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

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OR ☒ Correspondence address belowName **Kevin M. Kercher**Address **Blackwell Sanders Peper Martin LLP**Address **720 Olive Street, Suite 2400**City **St. Louis**State **Missouri**ZIP **63101**Country **US**Telephone **314-345-6000**Fax **314-345-6060**

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NAME OF SOLE OR FIRST INVENTOR:

☐ A petition has been filed for this unsigned inventor
 Given Name
 (first and middle [if any]) **Neil**

 Family Name
 Or Surname **Loxley**

 Inventor's
 Signature
N. LoxleyDate **17/12/01**Residence: City **Durham****GB3**

State

Country **GB**Citizenship **GB**Mailing Address **9 Whitesmocks Avenue**

Mailing Address

City **Durham**

State

ZIP **DH1 4HP**Country **Great Britain**

NAME OF SECOND INVENTOR:

☐ A petition has been filed for this unsigned inventor
 Given Name
 (first and middle [if any]) **Mark**

 Family Name
 Or Surname **Taylor**

 Inventor's
 Signature
Mark TaylorDate **18/12/01**Residence: City **Darlington****GB3**

State

Country **GB**Citizenship **GB**Mailing Address **71 Salutation Road**

Mailing Address

City **Darlington**

State

ZIP **DL3 8JW**Country **Great Britain**
☒ Additional inventors are being named on the 1 supplemental Additional Inventor(s) sheet(s) PTO/SB/02A attached hereto.

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DECLARATION — UTILITY OR DESIGN PATENT APPLICATION**ADDITIONAL INVENTOR(S)
SUPPLEMENTAL SHEET**

Attorney Docket Number: 717901.5

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NAME OF THIRD INVENTOR:

☐ A petition has been filed for this unsigned inventorGiven
Name John LeonardFamily Name
Or Surname WallInventor's
Signature

Date 18/12/01

Residence: City Newton Aycliffe

GB3

State

Country GB

Citizenship GB

Mailing Address 34 Cheltenham Way

Mailing Address

City Newton Aycliffe

State

ZIP DL5 4YD

Country Great Britain

NAME OF FOURTH INVENTOR:

☐ A petition has been filed for this unsigned inventorGiven Name
(first and middle [if any]) Graham VincentFamily Name
Or Surname FraserInventor's
Signature

Date 18/12/01

Residence: City Darlington

GB3

State

Country GB

Citizenship GB

Mailing Address Whitehouse Farm Cottage Heighington

Mailing Address

City Darlington

State

ZIP DL2 2XQ

Country Great Britain

☐ Additional inventors are being named on the supplemental Additional Inventor(s) sheet(s) PTO/SB/02A attached hereto.

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